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FINAL REPORT

**A PROGRAM OF
HIGH-RESOLUTION
X-RAY ASTRONOMY
USING
SOUNDING ROCKETS**

CONTRACT NO. NASW-2292

REPORT PERIOD:
15 MAY 1971 - 30 AUGUST 1972

PREPARED FOR:
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
NASA HEADQUARTERS
WASHINGTON, D.C. 20546

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Final Report

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Prepared for:

National Aeronautics and Space Administration
NASA Headquarters
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FOREWORD

This document is a final progress report for Contract NASW-2292. The launch of two rockets carrying focusing X-ray telescopes and scientific results from the analysis of data are described. Previous quarterly progress reports for this contract, ASE-2834, 2862, and 2963 describe the refurbishment, new designs, testing and calibration of the payloads. The sum total of the quarterly progress reports and this document are a comprehensive description of our sounding rocket effort for the year.

We would like to acknowledge the support given to us by the Sounding Rocket Division of the Goddard Space Flight Center and the U. S. Navy firing crew at the White Sands Missile Range.

1.0 INTRODUCTION

This document is a final progress report for contract NASW-2292. Two Aerobee 170 sounding rocket payloads were flown at the White Sands Missile Range with support from this contract: (a) a focusing X-ray collector on 31 March 1972 and (b) a high-resolution telescope on 4 August 1972. Data has been reduced from each of these flights. In the first flight both the rocket and the experiment instrumentation performed adequately, and it is clear that at least the minimum scientific objectives were attained. In the second flight the attitude control system (which is not part of the instrumentation covered in this contract) failed to point the telescope at the target for a sufficient length of time. However examination of final pre-flight checkout data and some flight data indicate that the instrumentation for this rocket payload was functioning according to expectations.

2.0 FOCUSING COLLECTOR ROCKET, 13.027 CG

2.1 Flight

NASA rocket 13.027 was brought to the field at the White Sands Missile Range on March 1 for a flight originally scheduled for March 10, 1972. Pre-flight calibration, the horizontal, and vertical checks were successfully completed. However during the night of 10 March a range safety receiver behaved peculiarly during the five-hour check. On the basis of the range safety receiver anomaly, the flight was cancelled and rescheduled for the night of 31 March 1972. The rocket was fired at 22:05 MST (5:05 UT, 1 April 1972).

The rocket attained a maximum altitude of 120 miles which was close to the pre-flight prediction.

2.2 General Performance of the Instrument during Flight

All systems operated well in flight. Timer-controlled electro-mechanical functions such as camera start, nose cone ejection, and counter door open occurred on schedule. The counters and all electronics maintained their integrity. The presence of cosmic X-ray sources in the Vela-Puppis region was evident in the real-time data records. Although the quality of the TM reception could not be termed excellent, there was sufficient redundancy in the number of receivers to cover the entire flight adequately.

There was one instrument problem. Background levels in all of the counters were considerably higher than expected. Our conclusion at the present time is that electromagnetic interference (EMI) from the transmitter into the pre-amplifiers was the cause of this effect. Our subsequent effort to reduce the effects of the EMI were successful. This is discussed in a later section. The net result of the EMI is that background levels in the equivalent energy band 0.1 - 0.3 keV are about twice or three times as expected. Background levels in the energy interval 0.5 - 1.5 keV are less than twice as high as expected. Consequently there is little practical effect with respect to our primary objective, mapping of the X-ray distribution of two rather strong sources, Vela X and Puppis A. Signal to noise was still excellent. However there is a sensitivity loss of about a factor of two for detecting new sources which was one of the secondary objectives of the experiment.

All systems continued to function at least until signal was lost at severance.

2.3 Recovery of the Payload

The payload was recovered successfully about twelve hours after the firing. Some damage was sustained by the structure. The nose section

was deformed as it apparently struck a rock. Three of the 14 glass reflecting plates were broken. The remainder of the payload was undamaged, including the counters, gas system, and aspect cameras. In order to fly again, the nose section of the payload structure should be re-built and at least three mirror plates should be replaced.

2.4 Analysis of Data

Flight aspect film from both cameras was developed. Both films were good so that one was sufficient to provide proper aspect information. Analysis of the aspect showed that the actual initial celestial position of the rocket was off by 3.5° from the intended position. This offset propagated without further error through all but the last maneuver. However the combination of a sufficiently large field of view for the instrument, $2^{\circ} \times 9^{\circ}$, plus the large range given to our maneuvers did allow us to cover the intended region of the sky adequately. The last roll maneuver of the rocket was off by $\sim 25^{\circ}$ so that a subsequent long pitch maneuver of 70° was off considerably from the desired position which included IC443 and the Crab Nebula. Thus, two minor experimental targets were not observed.

Computer compatible digital records of all the flight data were sent from the New Mexico State group at the WSMR. Also, tapes containing pulse height calibration data with various X-ray sources were provided. Twenty minutes of calibration data had been recorded several weeks before the actual flight.

Our initial effort was directed to reducing the effects of the EMI. It was apparent that several of the EMI induced events occurred simultaneously in more than one detector element or proportional counter wire. Thus, all events were figuratively struck from the records when they occurred simultaneously with an event in adjoining wires. This criterion reduced the background levels by about a factor of 3.

3.0 SCIENTIFIC RESULTS FROM THE FOCUSING COLLECTOR FLIGHT

3.1 Analysis of Vela-Puppis Data

The flight consisted of the following maneuvers. Two scans (back and forth) across the Coma Cluster of galaxies at a rate of $0.1^{\circ}/\text{sec}$, two almost mutually perpendicular scans across the Vela X- Puppis A supernova remnants at a rate of $0.32^{\circ}/\text{sec}$ and a scan from the Vela to Orion region at a rate of $2^{\circ}/\text{sec}$.

A study of the X-ray structure Vela X-Puppis A S. N. R. 's was the primary objective of the rocket flight.

Results have been obtained for the primary objective, the Vela X-Puppis A structure. A preliminary report was presented at the A. A. S. Meeting in East Lansing, Michigan, 18 August 1972.

Figures 1 and 2 show the variation of count rate versus angle during the scan across the Vela-Puppis region. Data is shown in two energy bands 0.1 - 0.3 and 0.5 - 1.5 keV. It is evident from these data that there is indeed intense X-ray emission from two supernova remnants, Vela X and Puppis A and that the X-ray emission is of a finite angular extent. In the case of Vela X the X-ray emission is from a region $5^{\circ} - 6^{\circ}$ in diameter and in the case of Puppis A the angular diameter is $.75^{\circ}$. Vela X is detectible in both energy bands but Puppis A is seen only in the higher energy band. It is evident that the structure of Vela X is not identical in both bands. In Figures 3 and 4 the count rate data in the band 0.1 - 0.3 keV for the two scans is superimposed upon a photograph of the optical filamentary structure in $H\alpha$ light. The optical photograph was taken at Cerro Tololo by Bart Bok of the Steward Observatory. The X-ray emitting region is considerably larger than the region shown on the photograph and evidently the regions of the

supernova remnant which are bright in X-rays do not coincide with the bright optical filaments. Also the center of the X-ray emission is considerably to the east (larger right ascension) of PSR833-45, a radio pulsar which is believed to be a neutron star remnant of the supernova explosion that resulted in the production of the X-ray emitting region.

The data in the energy band 0.5 - 1.5 keV is superimposed upon a composite 2650 MHz radio map of Vela X and Puppis A (D. K. Milne Aust. J. Phys. 21, 30, 1968, and D. K. Milne and E. R. Hill, Aust. J. Phys. 22, 211, 1969) in Figure 5. The radio map has been embellished in such a way as to emphasize its resemblance to a popular character. Puppis A is quite bright in this X-ray band. The relative surface brightness of Puppis A to Vela X is about an order of magnitude larger than Vela X in 0.5 - 1.5 keV X-rays.

In neither of the two energy bands does there seem to be any evidence for point sources in the vicinity of the remnants. In particular PSR833-45 does not appear above the continuum background.

3.2 Conclusions from Vela-Puppis Data

- a. Vela X is intense in both energy bands 0.1 - 0.3 keV and 0.5 - 1.5 keV. Its angular diameter is 5° - 6° with considerable structure.
- b. The region of intense X-ray emission in Vela X does not coincide with the bright optical filaments.
- c. Puppis A has an angular diameter of 0.75° .
- d. Puppis A is detectible only in the band 0.5 - 1.5 keV and its spectrum is harder than Vela X. The failure to detect Pup A at lower energies indicates that its distance probably exceeds 1500 pc.
- e. We see no evidence for point sources in this region.

Table I summarizes the X-ray characteristics of 3 soft X-ray emitting supernova remnants, one of which, the Cygnus Loop, was observed on a previous rocket flight (13.012 CG) with a similar instrument.

4.0 STELLAR TELESCOPE ROCKET FLIGHT

The objective of the stellar telescope sounding rocket flight 13.030 CG was to locate the source Cygnus X-1 to an accuracy of about 10 arc seconds. An inflight alignment calibration was required to achieve this precision, and Sco X-1 was to be observed for this purpose. The rocket attitude control system was programmed to result in 40 seconds observation of Sco X-1 followed by at least 100 seconds observation of Cygnus X-1. Unfortunately the pointing system provided only about 5 seconds of stable pointing on Sco X-1, and consequently the scientific objectives were not achieved. The rocket payload functioned properly during the flight, and photons from Sco X-1 were detected. The most important result from the flight is the verification of the image intensifier function in flight, both by detection of a stellar X-ray source and by on-board radioactive source calibration. The low background levels typical of the laboratory also were obtained in flight.

The image intensifier for this flight was the Bendix Cheveron device, which is a sequential assembly of two microchannel plates cut at different bias angles to avoid ion feedback. A photograph of this assembly is shown in Figure 6. The cheveron device can have a much higher gain than the single plate multipliers previously flown in this payload, and we currently plan to use this detector in the HEAO-C program. Consequently, its proper functioning through the rocket test procedures and launch environment provides a useful and favorable test of a quasi-prototype of the HEAO-C

TABLE I

X-RAY CHARACTERISTICS OF THREE SUPERNOVA REMNANTS

	<u>Vela X*</u> 5° - 6°	<u>Puppis A*</u> 0.75°	<u>Cygnus Loop**</u> 2.8°
Any Diameter			
Integrated Intensity 0.1 - 0.3 keV	4.8 c/cm ² -sec	< 0.16	5
Integrated Intensity 0.5 - 1.5 keV	8.7	4.2	8
X-ray Surface Brightness 0.5 - 1.5 keV	0.287 c/cm ² -sec-deg ²	8.4	1.0
Relative Surface X-ray Brightness 0.5 - 1.5 keV	1	29	3.5

*Observed this flight, 13.027

**Observed in 13.012

imaging detector. The alignment procedures developed during the preparation of the rocket payload also will benefit future X-ray telescope experiments.

The image intensifier in the payload at the beginning of the White Sands field trip was destroyed as a result of an accidental exposure to air while in operation, and it was necessary to change image intensifiers two days before the flight. A pre-flight alignment measurement of the aspect camera and new X-ray image intensifier was not performed, and consequently the absolute alignment is only known to an accuracy of about 3 arc minutes at this time. The rocket has not been disturbed since the flight, and a new alignment measurement will be made as part of the final data reduction. This will result in an estimate of the source location accuracy which can be obtained with this rocket payload.

The rocket payload appeared to function normally during the flight except for:

- a. The ion pump current monitor read its maximum value, even after the vacuum door opened. This indicates that the vacuum pressure was too high for the ion pump to pump efficiently; under these conditions the pump itself can be a source of gas. The poor vacuum probably resulted from material being shaken off of the ion pump walls during launch.
- b. The image intensifier high voltage monitor showed evidences of high loads for short periods during the first 10 seconds after the turn-on of the image intensifier. The flight film showed masses of individual spots at these times; we believe that the system was still outgassing ion pump products.

The X-ray image intensifier recovered to low background levels by 10 seconds after turn-on, and performed normally after that time and including the Sco X-1 observation period and the radioactive source calibration at the end of the flight.

The aspect camera functioned properly during the flight, and three 6th magnitude stars were observed in the field of Sco X-1. The final aspect determination will be based upon these stars together with the images of the X-ray focal plane fiducial lights, which also functioned properly and were photographed on each exposure. The absolute aspect determination of course will require a new measurement of the X-ray detector and aspect camera alignment as discussed above.

Three X-ray image intensifier exposures from the Sco X-1 portion of the flight, and also one typical frame with no known source in the field of view are shown in Figure 7. The three images are not in exactly the same location as a result of vehicle drifts and the finite resolution of the X-ray telescopes. The slightly different positions show that these events cannot be attributed to a single channel failure such as a hot spot. The location of the cluster also is consistent with the expected position of Sco X-1 to within the presently known alignment accuracy. We are confident that these three images resulted from Sco X-1 as a result of their time during the flight, their location, the fact that they are not exactly coincident, and the low-background levels observed at other times during the flight.

In conclusion, although the scientific objectives were not achieved, a very valuable instrument performance verification was obtained, and better X-ray imaging experiment procedures were developed as a result of this sounding rocket flight. The GSFC sounding rocket branch and also WSMR staff were most helpful and cooperative during this unusually difficult launch preparation period and provided thorough, resourceful, and qualified support to the flight.

FIGURE CAPTIONS

- Figure 1 Distribution of counting rate vs. angle in two energy bands for scan parallel to galactic plane. The strong peak in the band 0.5 - 1.5 keV is Puppis A. The 5° region is Vela X.
- Figure 2 Data similar to Figure 1 for scan perpendicular to galactic plane.
- Figure 3 The 0.1 - 0.3 keV data of Figure 1 superimposed upon photograph of optical filaments taken by B. Bok of Steward Observatory. The arrow indicates the direction of scan but the actual scan line was displaced several degrees relative to the line shown. The X-ray instrument is one dimensional. A contribution can come from anywhere within the region enclosed by the dotted lines.
- Figure 4 Same description as in Figure 3 caption for 0.1 - 0.3 keV data of Figure 2.
- Figure 5 Data of figures 1 and 2 for 0.5 - 1.5 keV band is shown superimposed upon composite 2650 MHz radio map of Vela X and Puppis A. Radio maps were reported by Milne (Aust. J. Phys. 21, 201, 1968) and Milne and Hill (Aust. J. Phys. 22, 211, 1968). An imaginative artistic treatment was given to the radio maps.
- Figure 6 Photograph of Bendix Cheveron microchannel device.
- Figure 7 Three X-ray image intensifier exposures from the Sco X-1 portion of Flight 13.030 and one typical frame with no known source in field of view.

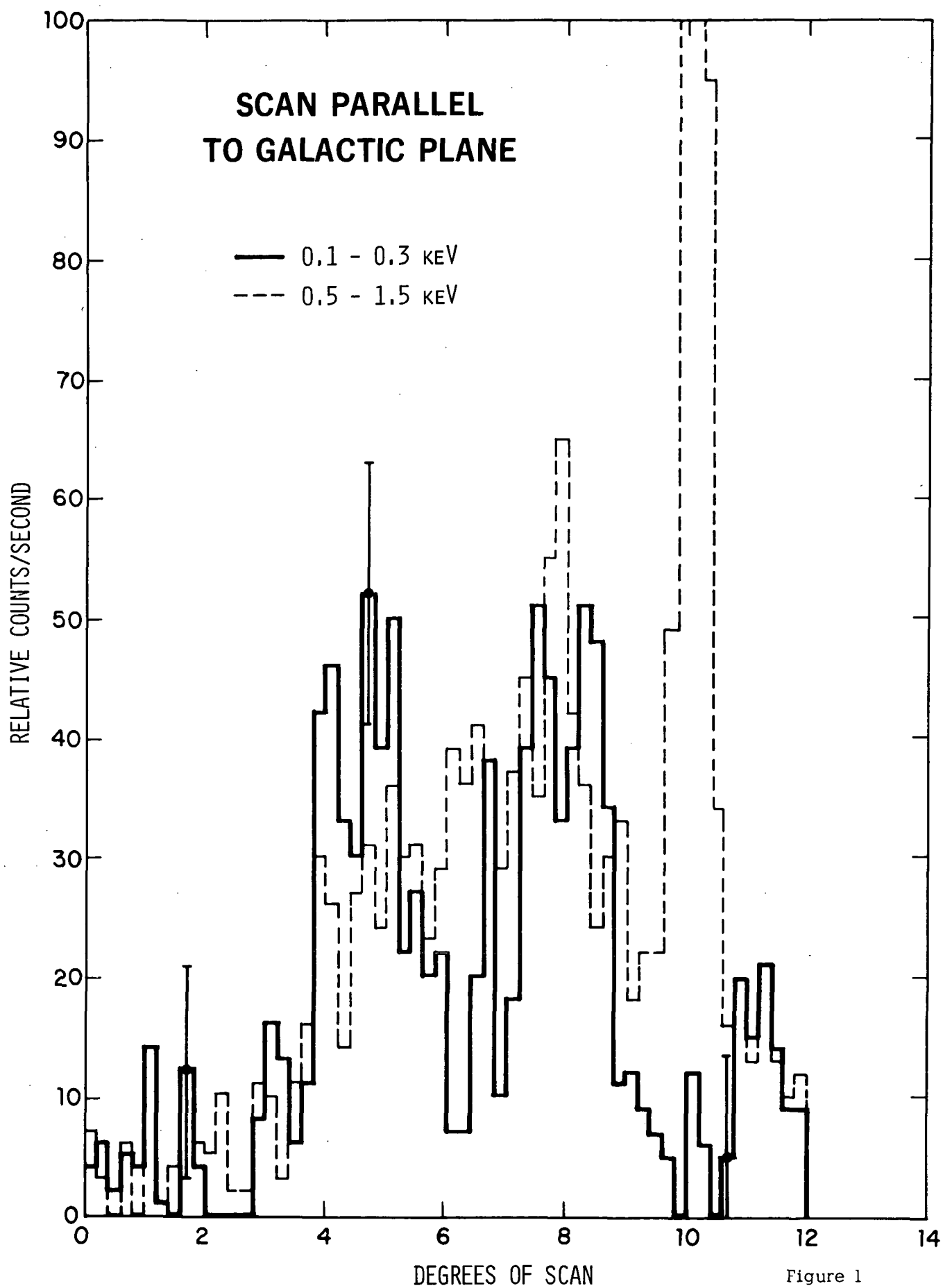


Figure 1

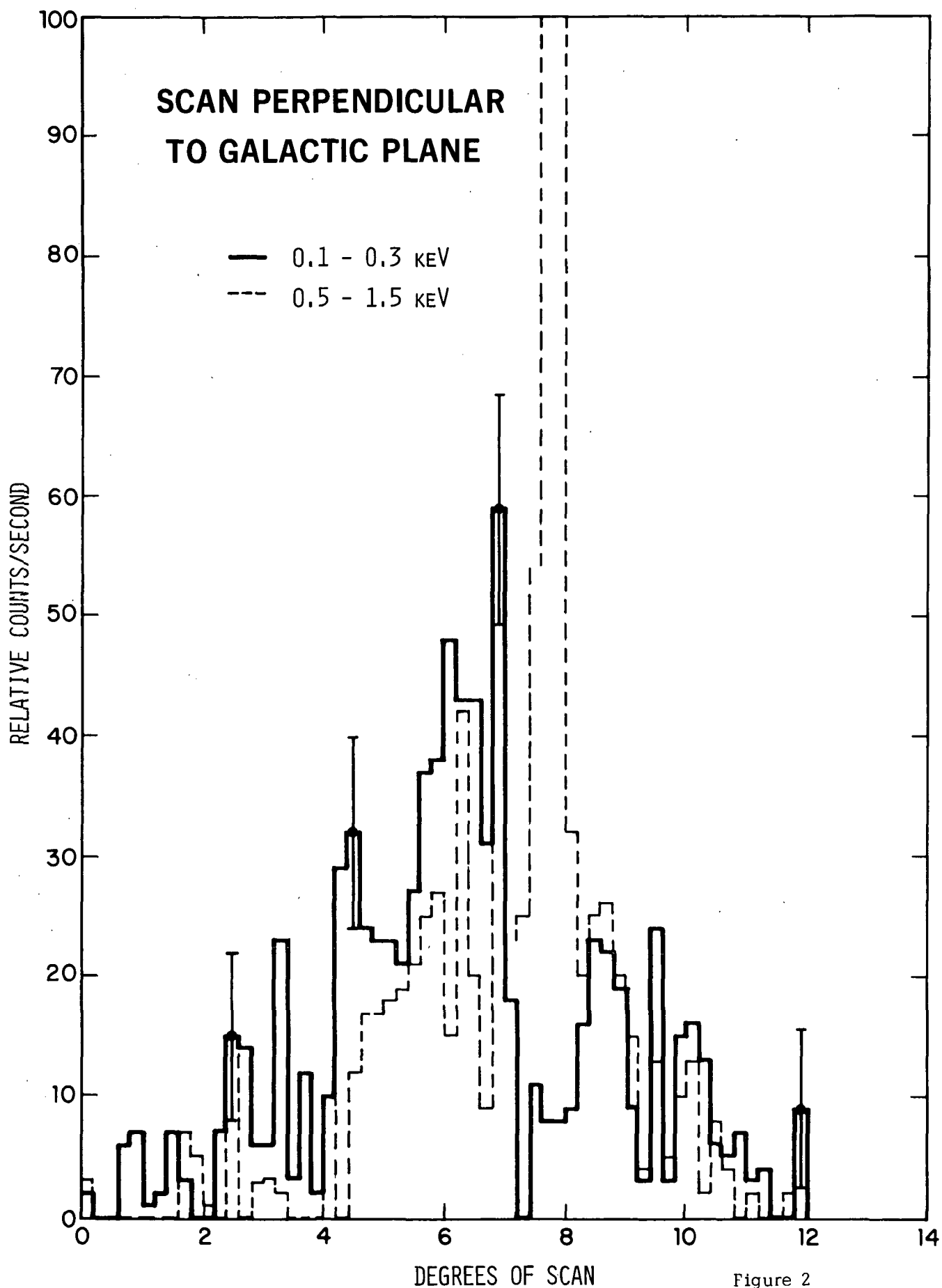
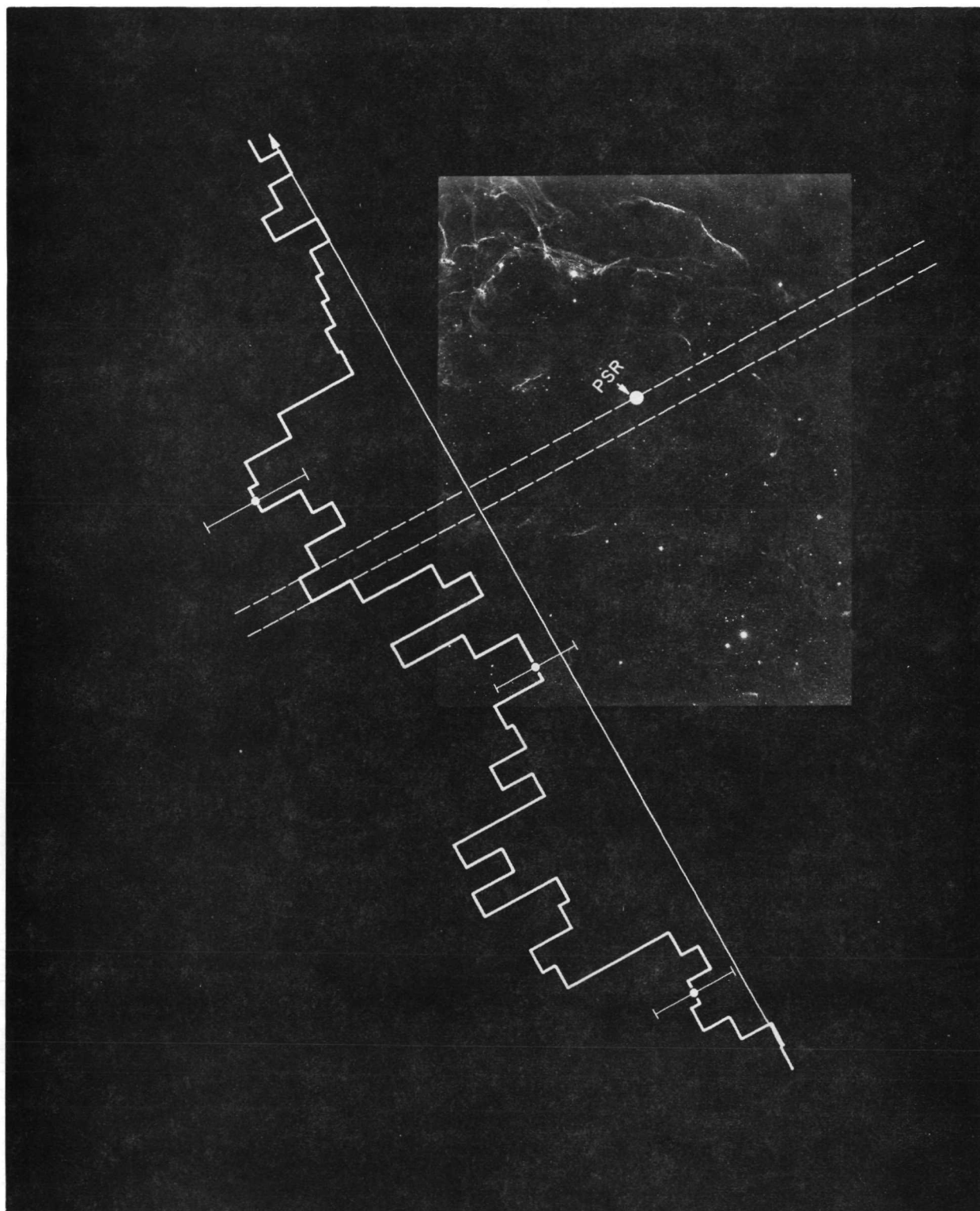
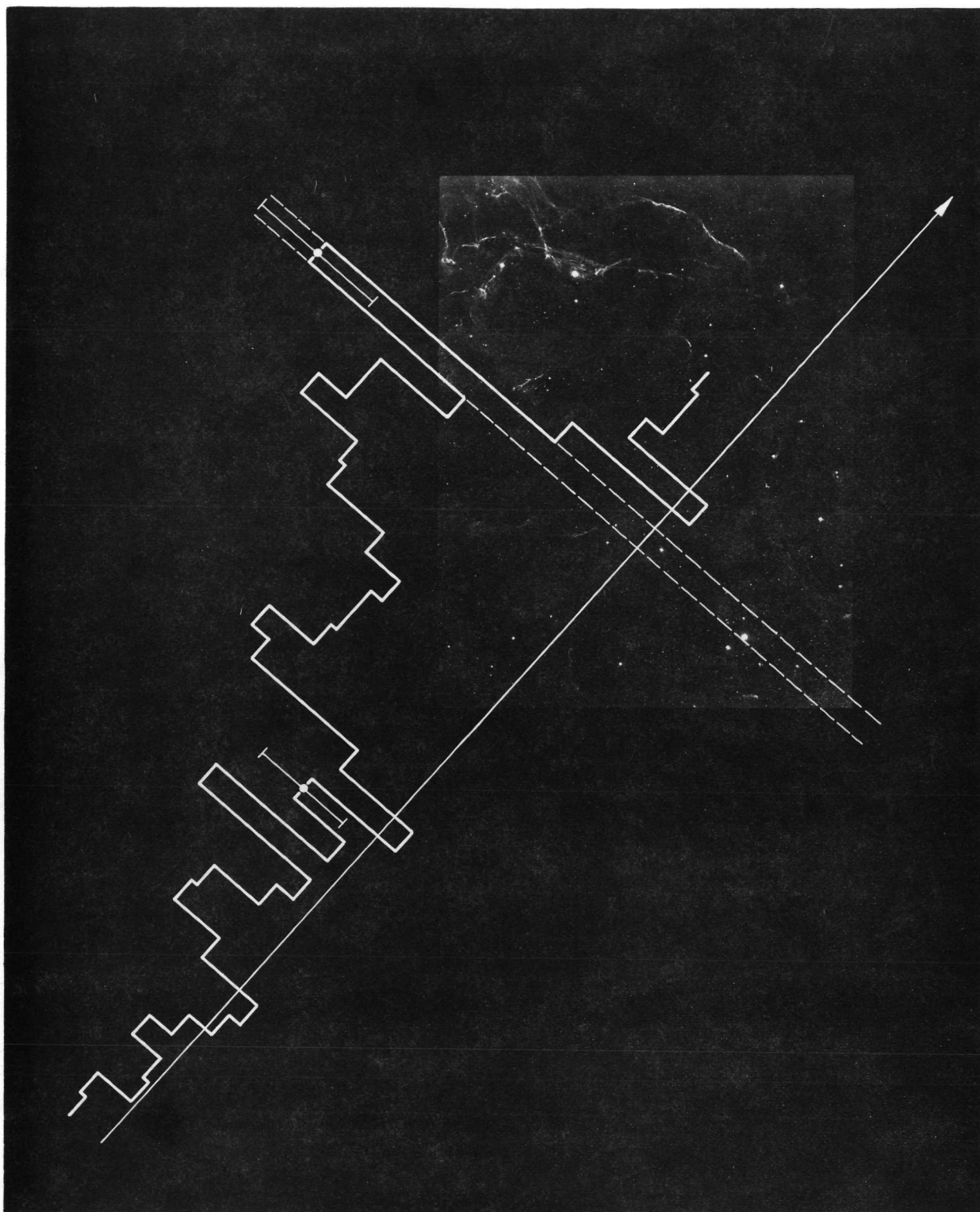


Figure 2



DT-111

Figure 3



DT-113

Figure 4

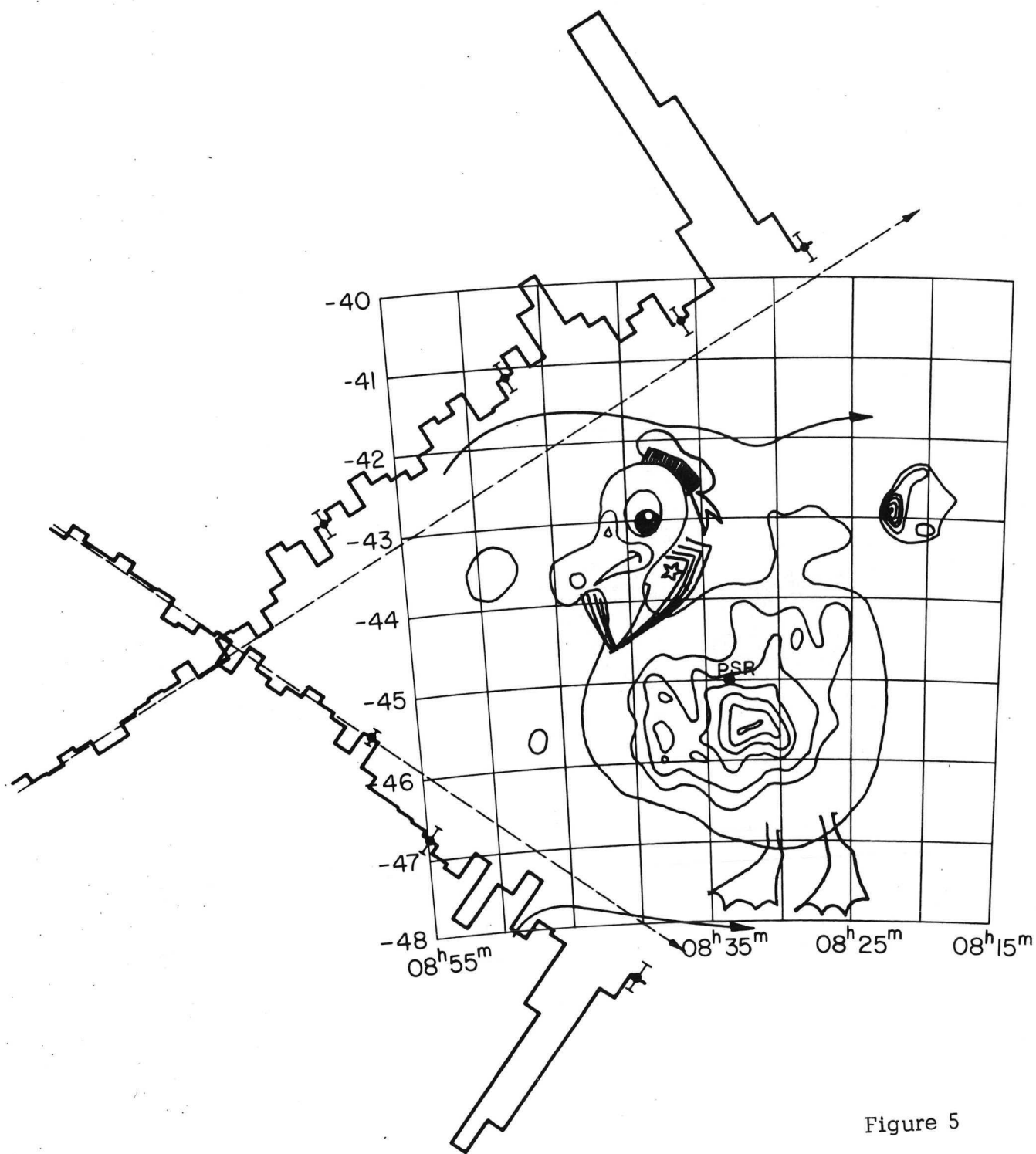


Figure 5

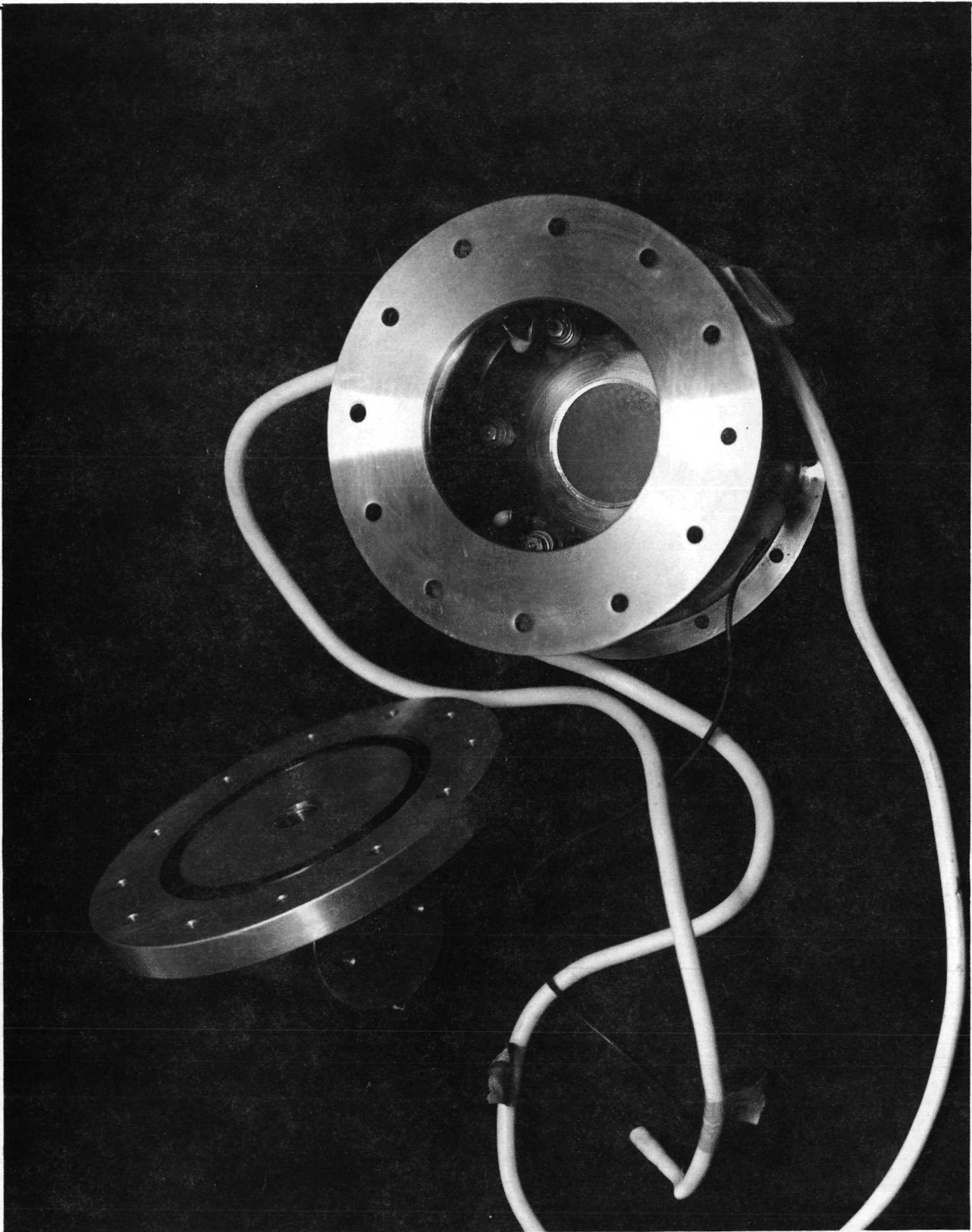
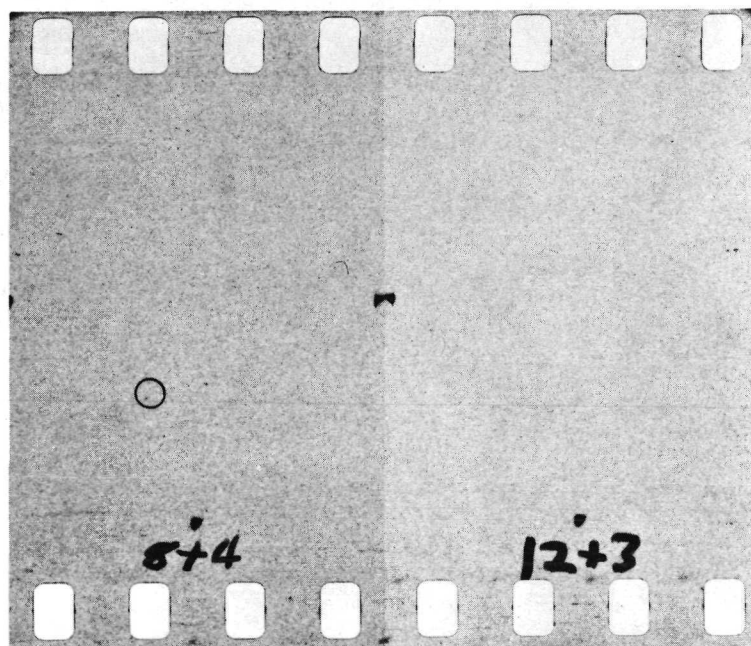
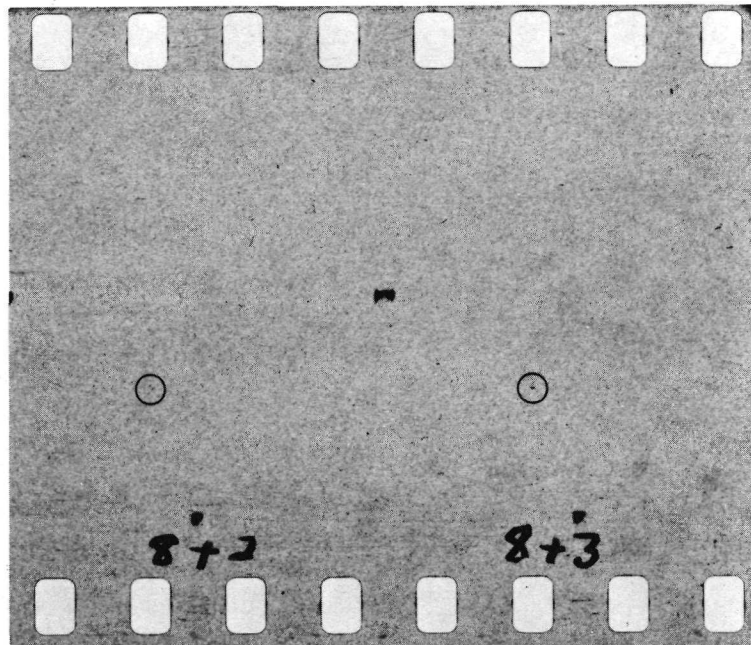


Figure 6



EG-027

Figure 7